300A 650V 70 um Thin IGBTs with Double-Sided Cooling

Hsueh-Rong Chang [1], Jiankang Bu [1], George Kong [2] and Ricky Labayen [3]
[1] Automotive Power Switches Development, [2] Temecula Manufacture Center, [3] Power Device Characterization Lab.
International Rectifier Corp. 101 N. Sepulveda Blvd, El Segundo, CA 90245
Phone: 310-726-8854, Email: hrchang1@irf.com

***Abstract*— Large IGBTs with a current rating of 300A and a blocking voltage of 650V on ultra thin wafers have been successfully developed with double-sided cooling capability. The deposition of solderable metals on the front and back sides of the IGBT produced flat thin wafers with less than 2 mm warpage and good mechanical yield. A large reduction of on-state voltage drop 390 mV at 300A is achieved in a wirebond-less Cu-clip package. The combination of lower on-state voltage drop and larger heat exchange area increases the IGBT current carrying capability by 200%.**

I. INTRODUCTION

The demand for high voltage and high current in hybrid electric vehicles (HEVs) presents technical challenges for power conversion beyond those normally associated with vehicle electrical and electronic systems. An increasing demand for fuel efficiency warrants light weight and small volume power control unit (PCU) in HEV [1, 2]. Conventional IGBT power modules use wire bonds which is the common site of module failures due to coefficient of thermal expansion (CTE) difference, and is the limiting factor for module life. IGBTs with dual solderable metals on top and bottom of the die offer a wirebond-less assembly option with enhanced reliability and lower manufacturing cost [3, 4]. In addition, it allows double sided cooling with significantly larger heat exchange area, thus improving thermal management when compared with wire bonds used in traditional power modules.

In this paper, we report the development of large IGBTs with a current rating of 300A, a blocking voltage of 650V, and double-sided cooling capability on ultra thin wafers. A process for the deposition of solderable metals on the front and back sides of the IGBT was developed to produce flat thin wafers with less than 2 mm warpage and good mechanical yield. A wirebond-less Cu-clip package were used to demonstrate significant lower on-state voltage drop of the IGBTs with solderable front metals (SFM) and large increase in heat exchange area, thus resulting in higher current carrying capability by 200%.

II. PROCESS CHALLENGES AND SOLUTIONS

IGBT with field stop (FS) structure offers a superior trade-off between static and dynamic losses as compared with Punch-Through (PT) - IGBTs [5]. The typical thickness of 650V FS IGBT is in the range of 65 – 75 um. Thin wafers could be severely warped due to compressive or tensile metal stress, thus resulting in high mechanical breakage and poor yield [6].

The IGBTs reported in this paper were processed following a normal planar IGBT process first till the aluminum was sputtered on the front side. After the deposition of the passivation layer, the solderable front metal (SFM) was sputtered and patterned, followed by a ultra-thin-wafer (UTW) grinding process and an implantation to form the buffer-layer on the backside of the wafer. Collector was formed by the implantation of boron followed by back metal processes. The composition of the solderable metals includes Ti-Ni-Ag. Cu-clip was chosen for contacting emitter pad to eliminate wire bonds and to enable double-sided cooling. Fig. 1 shows the side view of the IGBT. The SFM coverage over passivation layer is shown in Fig. 2.

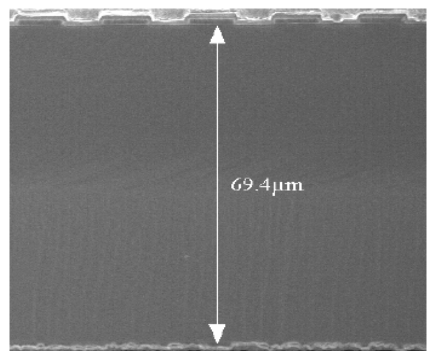


Fig. 1 Device structure.

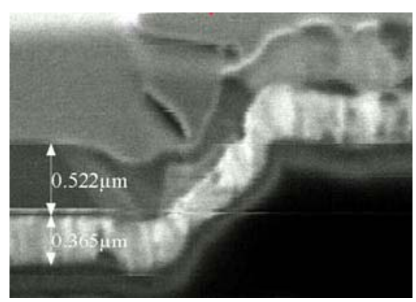
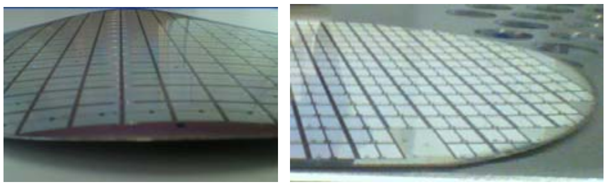


Fig. 2 SFM coverage over the passivation layer.



(a) (b)

Fig. 3 Standard process could lead to (a) compressive or (b) tensile stressed wafers.

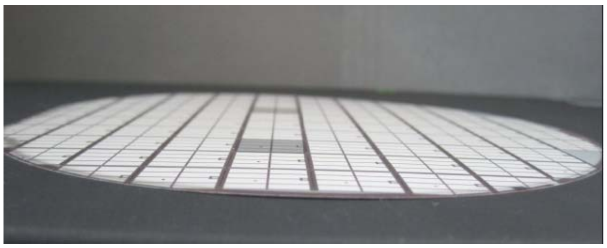
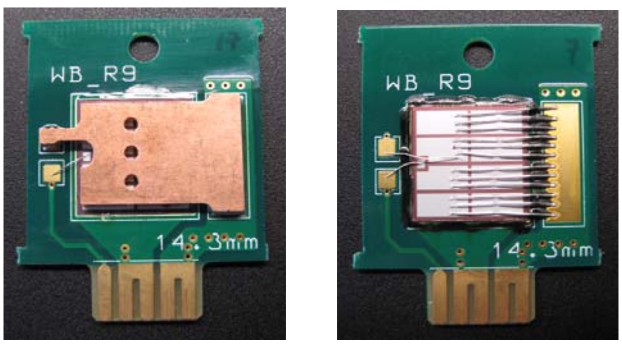


Fig. 4 Wafer with warpage less than 1 mm.



(a) Cu-clip IGBT. (b). Wire-bonded IGBT

Fig. 5 Top views of IGBTs packaged in Cu-clip (a) and wirebond (b).

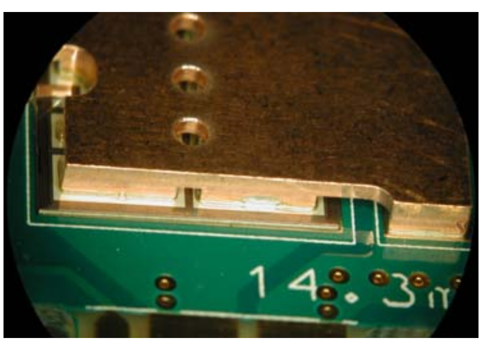


Fig. 6 A side view of Cu-clip IGBT

The metal Ni used in the solderable metal composition produces high surface stress on Si wafers, which poses tremendous challenges for the UTW process. Un-optimized metal deposition process could lead to high compressive or tensile stress, resulting in severely warped wafers, as shown in Fig. 3a and 3b. Wafers with warpage greater than 6 mm cannot be used in manufacturing process and electrical testing thereafter due to high risk on wafer breakage. The Zero-stress process is susceptible to metal peeling. To overcome these challenges, we have developed a novel stress control scheme to allow compressive stress balanced by the tensile stress at the end of the fabrication of the thin IGBT wafers. Fig. 4 shows the ultra thin IGBT wafer with near-zero-warpage.

Cu-clip package has been widely used in microelectronic components to eliminate wire bonds and to enhance device performance and reliability. But it has not been explored in the assembly of high voltage IGBTs. In this study, we use the wirebond-less feature of Cu-clip to evaluate the performance improvement of large IGBT die. Fig. 5 shows the top views of the IGBTs packaged in Cu-clip and in wirebond configuration. Cu-clip was designed to perfectly fit the emitter pad. A side view of the Cu-clip IGBT is shown in Fig. 6. The Cu-clip has a thickness of 2mm. It significantly reduces the current spreading resistance at the emitter, thus resulting in low on-state voltage drop, Vceon.

III. ELECTRICAL PERFORMANCE AND DISCUSSION

1. Static Performance

Fig. 7 shows the IGBT die layout. The output characteristic is shown in Fig. 8. A large reduction of 390 mV in Vceon at Ice=300A was achieved for the Cu-clip IGBTs as compared with the IGBTs packaged with wire-bonds, as shown in Fig. 9.

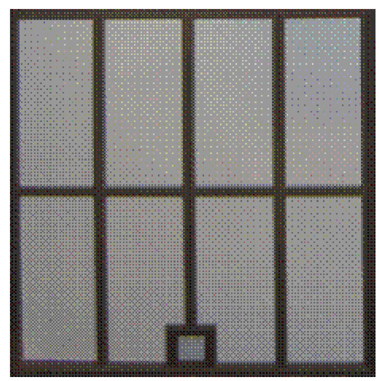


Fig.7 IGBT Die Layout.

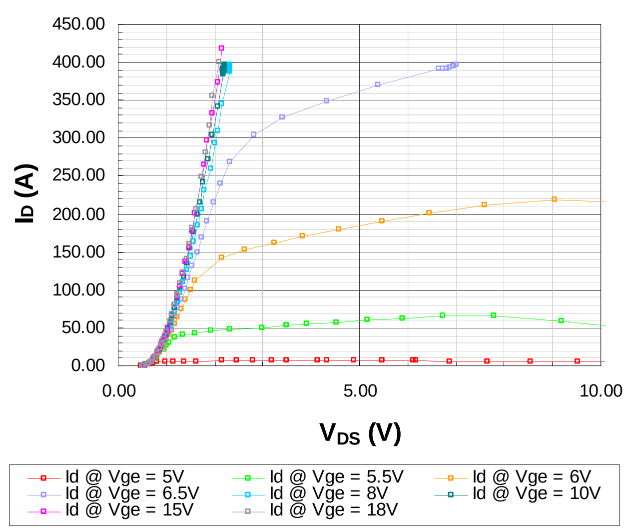


Fig. 8 Output Characteristics at 25C at various Vge.

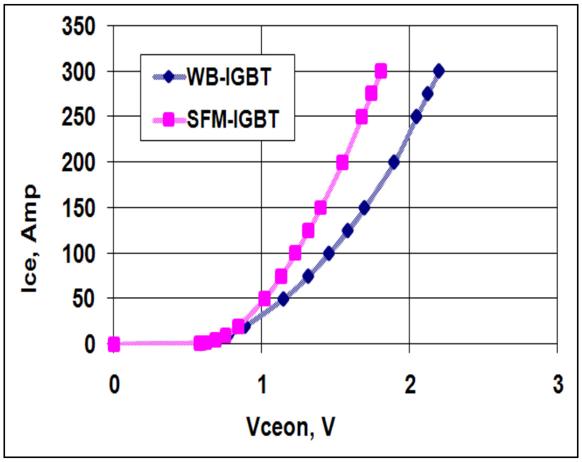


Fig. 9 I-V curves for WB-IGBT and SFM-IGBT.

Fig. 10 shows the breakdown voltage distribution of the ultra thin SFM IGBT wafers. The average breakdown voltage is 706V at 25C with 3 Sigma of 21V, which provides sufficient margin for 650V applications. The breakdown voltage is increased to above 800V at 150C, as shown in Fig. 11.

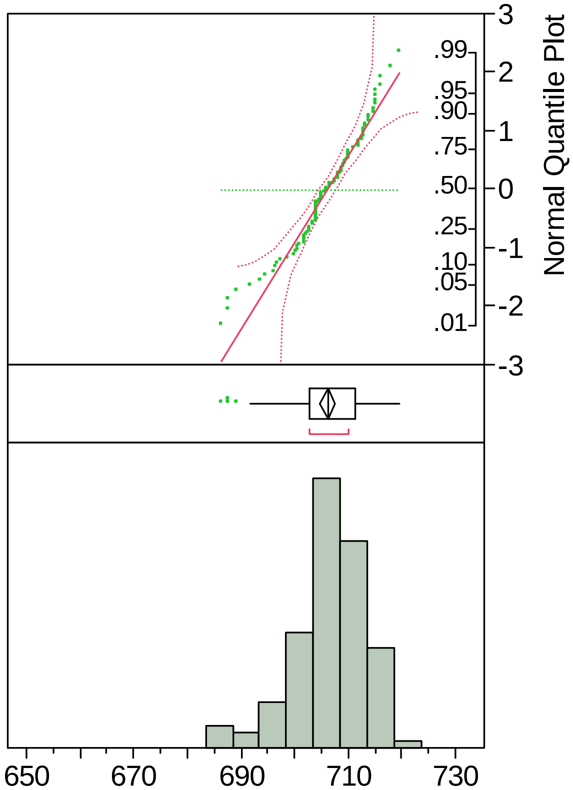


Fig. 10 Breakdown voltage distribution.

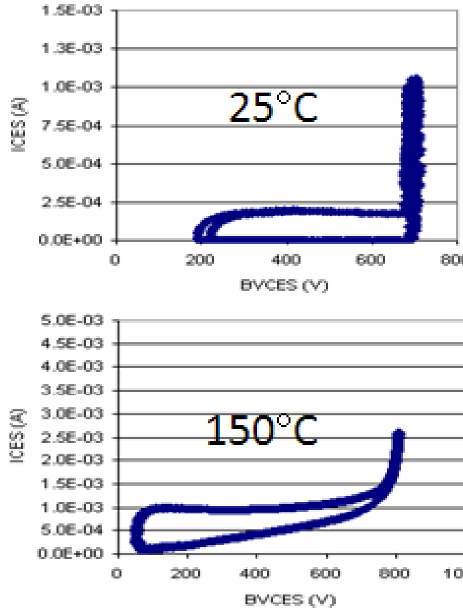


Fig. 11 Breakdown voltages at 150C for SFM- IGBTs with Cu clip.

2. Dynamic Characterization

Dynamic switching of the Cu-clip IGBTs was measured at Vcc=400V and Ic=300A. The current and voltage waveforms are shown in Fig. 12. The turn-off speed of the Cu-clip IGBTs is in the range of 200-215 ns at 25°C. Because no electron irradiation is used for lifetime control, the t_{fall} time does not vary much with temperature. The leakage current of the thin IGBTs is low at elevated temperatures, i.e., 4.5 mA at 600V and 175°C, enabling the operation at Tjmax of 175°C while the Tjmax is limited to 150C for the PT-IGBTs due to a rapid increase in the leakage current with increasing temperature.

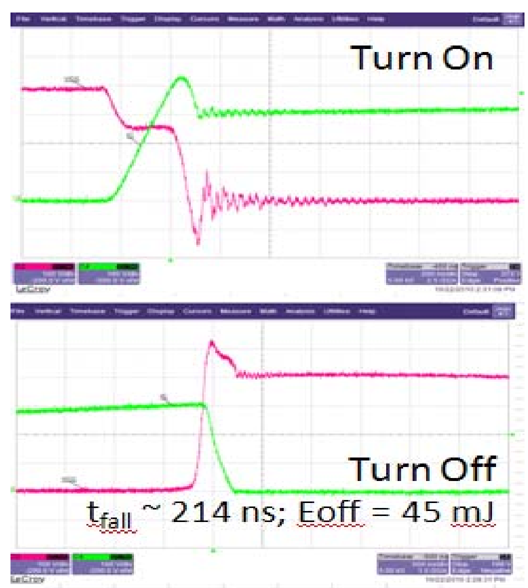


Fig. 12 Turn-on and turn-off waveforms of SFM - IGBT with Cu-clip. (Vcc=400V, Ice=300A, 25°C)

The thin IGBTs with dual solderable metals on top and bottom of the die enable double-sided cooling for effective heat removal. The junction-to-case thermal resistance of the SFM-IGBTs, $R_{\theta jc\_SFM}$ can be calculated by Eqn.(1). It is equivalent to a WB-IGBT in parallel to a top SFM emitter.

$$\frac{1}{R_{\theta jc\_SFM}} = \frac{1}{R_{\theta jc\_WB}} + \frac{1}{R_{\theta jc\_TOP}} \qquad (1)$$

In this study, the SFM coverage on the emitter pad is 67% of the die area. This leads to 40% reduction of $R_{\theta jc\_SFM}$ as compared with that of WB-IGBT's., thus significantly increasing the power handling capability of the SFM-IGBT. In addition, the SFM IGBT has a much lower Vceon than WB-IGBT, as shown in Fig. 9. At Vceon=1.8V, the SFM-IGBTs would conduct 300A while only 175A for the WB-IGBT's. The combination of lower Vceon and double-sided cooling allows 200% improvement in the SFM-IGBT power handling capability as compared with conventional WB-IGBTs.

The wirebond-less IGBTs offer additional advantage in terms of reliability. Conventional IGBT power modules use wire bonds which is the common site of module failures due to CTE difference, and is the limiting factor for module life. The wirebond-less SFM IGBTs were evaluated in power cycling test with $\Delta T=100°C$. The preliminary results are very encouraging. The number of cycles is increased by 260% for the wirebond-less IGBTs as compared with the wire-bonded IGBTs.

IV. CONCLUSION

We have successfully developed high current, high voltage IGBTs on ultra thin wafers with double-sided cooling capability. Wirebond-less IGBTs with Cu-clip contacted emitter exhibit significant reduction of on-state voltage drop as well as enhanced reliability. The feature of double-side cooling allows 67% increase in the heat exchange area. The combination of lower Vceon and larger heat exchange area leads to 200% improvement in the IGBT power handling capability as compared with the conventional wire-bonded IGBTs.

ACKNOWLEDGMENT

Authors would like to acknowledge IR Temecula management and engineering team for their support.

REFERENCES

[1] T. Kikuchi, et. Al., EVS21, 2005

[2] R. Hironaka, et. Al., EVS22, 2006.

[3] T. Burress, International Energy Conversion Engineering Conference,Nashville, Tennesse, June 2010.

[4] "Power EV-HEV 2010 – power electronics in Electric and Hybrid Cars," Yole development, France, 2009.

[5] T. Laska, et al, "Short Circuit Properties of the trench/Field-Stop-IGBTs – Design Aspects for a Superior Robustness', Proc. ISPSD'03, 2003.

[6] T. Laska, M. Matschitsch, W. Scholz, "Ultra thin-wafer technology for a new 600 V-NPT-IGBT", ISPSD '97.